Efficient Waste Management in a Smart City

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Abstract. National projects for the development of the Russian Federation, including in the field of digitalization, aimed at creating a comfortable ecologically pure urban environment are presented. The evolution of the “smart city” concept is briefly presented: from technological to humanitarian view. Some examples of smart solutions in terms of ecology are given. Indicators of the smart city are analyzed, environmental characteristics are highlighted. The data on Yekaterinburg and actual directions of automation for solving environmental problems in the Sverdlovsk region are shown. The logistical task of garbage picking in multi-agent systems technology is formalized and the model example is presented in the Any Logic simulation system.

1. Introduction

Presidential Decree of May 7, 2018 No. 204 "On the national goals and strategic objectives of the development of the Russian Federation for the period up to 2024" identified 12 areas of the country's strategic development, for which relevant national projects have been developed [1]. National projects affect all major areas of citizens' life, among them such projects as “Demography”, “Education”, “Healthcare”, “Culture”, “Science”, etc. In this context, we especially note the national projects “Ecology”, “Housing and urban environment”, “Digital economy of the Russian Federation”.

The national project “Ecology” [2] occupies an important place, since the overall environmental situation in Russia is unsatisfactory. The environment in cities and adjacent areas, where 74% of the population lives, is exposed to a significant negative impact from industrial, energy, transport and capital construction facilities. The situation with the accumulation of production and consumption wastes is catastrophic. Annual economic losses due to environmental degradation are 4-6% of GDP. The national project will be implemented in five areas: “Waste”, “Water”, “Air”, “Biodiversity”, “Technology”.

The key objectives of the national project “Ecology” are the effective handling of production and consumption waste, including the elimination of all unauthorized landfills identified within cities, and the reduction of air pollution in large industrial centers. Attention is also focused on improving the quality of drinking water, cleaning and preserving water bodies, unique water systems, preserving biological diversity and creating new specially protected natural areas, ensuring the balance of deforestation and reproduction of forests. In accordance with these goals, 11 federal projects have been developed, including “Clean Country”, “Integrated Solid Municipal Waste Management

System", "Infrastructure for Waste Management 1-2 Hazard Class", "Clean Air", "Clean Water" and others, for which the relevant ministries are responsible.

All these measures are closely related to improving the quality of the urban environment. The Russian government has approved the methodology for calculating the quality index of the urban environment, from which the size of regional subsidies will depend on from 2020. The index was developed by the Ministry of Construction of Russia in the framework of the national project "Housing and Urban Environment" based on 36 indicators. These include the share of emergency housing and the diversity of residential development, the diversity of cultural, leisure and sports infrastructure, the development of the transport system, road congestion and the number of people killed in road accidents, the pedestrian accessibility index and others. An important parameter is the level of landscaping. The Ministry of Construction of the Russian Federation will have to annually ensure the formation of an index of quality of the urban environment.

In March 2019, the Ministry of Construction and Housing and Communal Services of the Russian Federation approved the Smart City standard. The section "Intellectual systems of environmental safety" of this document assumes the development of systems for monitoring the quality of air and water in the online mode. The automation of the management system for solid municipal waste management is also relevant.

Next, we will show how this problem is solved abroad and in Russia, and we will also offer an original approach to automating the management of garbage collection on the basis of a multi-agent modeling approach.

2. Evolution of the concept of "smart city"

The problem of the constant increase in environmental pressure on cities as a result of continuous urbanization and increasing requirements for the quality of the urban environment is called upon to resolve modern technologies of a smart city. In October 2018, the Ministry of Construction and Housing and Communal Services of the Russian Federation approved the passport of the departmental project of digitization of the municipal economy "Smart City", according to which the regions, including the Sverdlovsk region, are actively developing ways to implement this project. In March 2019, the Smart City standard was approved – Basic and additional requirements for smart cities. "Smart City" is developing in line with the national project "Digital Economy of the Russian Federation" [3] and "Strategies for the Development of the Information Society in the Russian Federation for 2017-2030".

The concept of a smart city, formed in the early 2000s, evolved from a predominantly technological approach to a humanitarian one. The new model of the smart city provides not only various ways of applying smart technological solutions, but also the active involvement of residents in their development. A modern smart city is a municipality with a well-developed technological infrastructure, where human life acquires a new quality thanks to smart solutions. This is a systematic approach to the use of information technologies based on data analysis for making management decisions for the purposes of sustainable development and ensuring high living standards.

The British Standards Institute (BSI) describes the smart city as "the effective integration of physical, digital and human systems in an artificially created environment in order to ensure a sustainable, prosperous and comprehensive future for citizens".

At the international industrial exhibition "Innoprom", the Ministry of Construction of the Russian Federation announced an unusual and unique rating of Russian cities: they will be assigned an appropriate IQ. The higher the degree of penetration of digital solutions in the urban environment, including in the sphere of housing and public utilities and landscaping, provides the higher the IQ of the municipality.

3. Examples of smart environmental solutions

Smart solutions for a comfortable urban environment have already been implemented in different countries of the world. Let us show some examples.

The water quality control system in the largest reservoir in Eurasia, Kuibyshevsky, was developed by Airalab Rus, SMART Distributions and Togliatti State University. Using a solar-powered river drone that can move around the river, water quality parameters are measured using the technology of the Spanish company Libelium [4], one of the world's largest manufacturers of intelligent sensors and solutions based on them. In order to provide information on water quality to interested parties (via a web application), a blockchain-based platform and the Internet of Things (IoT) were used. Controlled parameters: water temperature, pH, dissolved oxygen content, electric conductivity of water, ions NH^4 + and NO^{3-}.

Management systems for garbage collection are part of the concept of a smart city [5]. They consist of remote sensors installed in garbage cans and specialized software. Sensors monitor the level of fullness of garbage cans and transmit data to the central server in real time. They are ultrasound and in most cases are powered by solar energy, which allows them to assess the level of fullness of garbage bins offline. The transfer process is carried out over the radio using built-in GPS and GPRS-modules. Further, the specialized software provides detailed detailing of the filling level of each container; on this basis, optimal plans for waste collection routes are built. This allows you to optimize staff working time, reduce the amount of fuel consumed by garbage trucks, reduce the number of purchased garbage collection machines, and reduce equipment and roadbed wear. As a result, according to analysts, the costs of utilities for garbage collection can be reduced by almost 40%.

The main suppliers of automation solutions for garbage collection are companies such as IBM Corporation, SAP SE, Waste Management, Enevo, BigBelly, and Compology. Smart garbage collection systems are implemented in the USA, Spain, UK, Finland. In Russia, the process of automating the collection of street garbage begins to develop.

For the centralized collection of systems for the automation of all sections in accordance with the standard of the smart city, a special resource has been created – the smart city solutions bank [6]. At the end of 2018 – the beginning of 2019, 4 systems appeared in the section “Intellectual systems of environmental safety”. Each of them has its own approaches and implementation features.

4. Analysis of Russian cities based on smart environment indicators

In 2017, the Moscow company National Research Institute of Technology and Communications (at the same time consulting center in the field of information and communication technologies) developed smart city indicators (26 parameters distributed in 7 key areas) and the corresponding methodology for analyzing Russian cities based on them [7]. The 16 largest cities in Russia were analyzed, Yekaterinburg ranked 4th in the degree of implementation of smart technologies. In such areas as smart finance, economics, technology, smart people, Yekaterinburg occupies high positions. In areas of smart management, infrastructure and the smart environment is on average and below average.

The direction of the smart environment was estimated on the basis of 2 indicators for which there were open data: the level of activity of residents and the city administration in eliminating illegal dumps and the level of development of monitoring systems and the prevention of threats to environmental safety.

In terms of smart environment indicators, neighboring regions are much more successful in working towards the environment: Novosibirsk, Krasnoyarsk and Chelyabinsk make up the top 3 cities according to these indicators, although they are close to Yekaterinburg in terms of climate and environmental situation.

At present, within the framework of the regional program “Smart Cities of the Sverdlovsk Region”, the development of intelligent environmental safety systems is underway. The complex system of digital development of the urban environment of the Sverdlovsk region involves the automation of the management system for solid municipal waste management. The matrix of elements of a smart city will optimize the routes of movement of specialized equipment to ensure efficient use of resources in the collection and disposal of waste, as well as carry out an automatic analysis of the costs of collecting, exporting and disposing of waste and rating taking into account investments in the construction of new infrastructure. Provision is also made to monitor the movement and operation of

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specialized equipment in the online mode. The organization of interaction between regional and municipal authorities, a regional operator for removal of municipal solid waste, waste carriers and landfill sites is needed.

5. Multi-agent approach to system formalization

Next, the proposed formalization of the problem of garbage collection in terms of technology multi-agent systems for subsequent simulation in the system AnyLogic. Figure 1 shows 3 types of intelligent agents that interact in order to optimize resources.

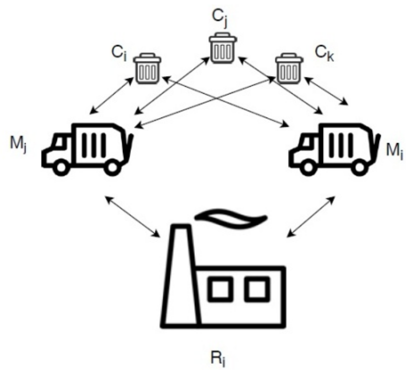

Figure 1. The model in terms of multi-agent systems

The control system for garbage collection is represented as a connected graph, where the vertices are agents, the edges are the connections between them. We distinguish three types of agents: garbage collection points ($C = \{c_i\}_{i=1}^{m}$), garbage collection machines ($M = \{m_i\}_{i=1}^{n}$), recycling sites ($R = \{r_i\}_{i=1}^{k}$). The limitations of the system are directly related to the limitations for each type of agent. The total capacity of the collection points should not exceed the total capacity of the recycling sites. We also introduce restrictions on the fullness of garbage collection points and recycling sites and then consider the sensors of each agent and its communication with other objects of the system.

$$f(x) = \begin{cases} \sum_{i=1}^{m} capacity(c_i) \leq \sum_{i=1}^{k} capacity(r_i), \\ \dfrac{\sum_{i=1}^{j} occupancy(c_i)}{\sum_{i=1}^{m} capacity(c_i)} \leq 0.95, \\ \dfrac{\sum_{i=1}^{l} occupancy(r_i)}{\sum_{i=1}^{k} capacity(r_i)} \leq 0.85. \end{cases}$$

Sensor “garbage collection point” – is a sensor of the current fullness. The agent is able to transfer this data to the agents of the “garbage collection machine” type. The main task of the agent “garbage collection point” is to get rid of the greatest possible amount of garbage during the day, that is, to minimize the time of “useless work”:

$$time\left(\frac{occupancy(c_i)}{capacity(c_i)} \geq 0.7\right) \rightarrow min.$$

The sensor of "garbage collection machines" – a sensor of the current fullness. The agent is able to transfer this data to agents of the type “garbage disposal site”, to receive and process data from “garbage collection points”, from “garbage disposal sites”. The tasks of the agents of the “garbage collection machine” include the transportation of the largest possible amount of garbage in the shortest time, that is, minimizing the “idle”, and at the same time reducing the cost of fuel:

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$$\begin{cases} time\left(\dfrac{occupancy(m_i)}{capacity(m_i)} \leq 0.7\right) \rightarrow min, \\ fuel(m_i) \rightarrow min. \end{cases}$$

“Garbage disposal sites” are able to receive and process data from “garbage collection machines”, as well as transfer potential load data to agents such as “garbage collection machines”. The task of “waste recycling sites” is to optimize waste recycling:

$$\begin{cases} time\left(\dfrac{occupancy(r_i)}{capacity(r_i)} \geq 0.9\right) \rightarrow min, \\ \dfrac{occupancy(r_i)}{capacity(r_i)} \rightarrow max. \end{cases}$$

This formalization is the basis for the subsequent modeling of autonomous intelligent agents in the Any Logic system.

Thus, the paper presents the results of research in the field of digitalization for the creation of a comfortable environmentally friendly urban environment in the "smart city" system. The actual directions of automation of solving environmental problems in the Sverdlovsk region are shown. The mathematical formalization of the logistic optimization problem when collecting garbage in the technology of multi-agent systems with the goal of modeling in the system Any Logic.

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